AXIAL CAPACITY OF PILES SUPPORTED ON INTERMEDIATE GEOMATERIALS

An MPART Research Proposal

Submitted by:

Dr. Robert L. Mokwa, P.E.

Assistant Professor
Department of Civil Engineering
Montana State University – Bozeman

Submitted on behalf of the Western Transportation Institute (WTI)

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1 Problem Statement

Pile foundations used to support bridges must be designed and installed to sustain axial and lateral loads without failing in bearing capacity, without suffering structural damage, and without undergoing excessive settlements. The axial load-carrying capacity of a driven pile is derived from friction or adhesion along the pile shaft, and by compressive resistance at the contact of the pile base with the underlying soil.

The process of deep foundation design for axial loads consists of a succession of intermediate steps, typically as follows:

1. Selection of pile type.
2. Determination of pile size.
3. Selection of pile driving system.
4. Specification of minimum pile length.
5. Establishment of a minimum driving resistance.

There are two general approaches for designing piles for axial loads: 1) those based on soil properties, and 2) those based on in-situ tests. Numerous analytical methods are available for estimating the static axial capacity of piles. These methods are well-documented in popular manuals and publications including: AASHTO (2005), Das (2004), Hannigan et al. (1996), and Prakash and Sharma (1990). Geotechnical engineers at the Montana Department of Transportation (MDT) use the computer programs DRIVEN and GRLWEAP to partially automate the analytical computations necessary to achieve the design steps listed above. The methods described in the referenced publications and computer programs typically differentiate subsurface materials into one of three material types: 1) cohesive soil, 2) cohesionless soil, or 3) rock. The current state of practice for evaluating pile capacity and for predicting pile driving characteristics for these materials is relatively well-established.

However, there is an additional type of geomaterial that does not nicely fit into one of the three basic material types. These materials are referred to in the literature as *intermediate geomaterials*, *formation materials,* or *soft rock*. Intermediate geomaterials can have a wide array of properties with characteristics ranging from stiff or hard soil to soft weathered rock, including shale, siltstone, claystone, and some sandstones. O'Neill et al. (1996) classify intermediate geomaterials into three categories:

1. Argillaceous geomaterials: heavily overconsolidated clays, clay shales, saprollites, and mudstones that are prone to smearing when drilled.
2. Calcareous rocks: limestone, limerock, and argillaceous geomaterials that are not prone to smearing when drilled.
3. Very dense granular geomaterials: residual, completely decomposed rock and glacial till with SPT N-values greater than 50 blows/18 in.

The first two categories consist generally of cohesive materials, while the third category consists primarily of cohesionless materials. Deposits of intermediate geomaterials from all three categories can be found in Montana.

The axial capacity, driving resistance, and long-term resistance of piles driven into intermediate geomaterials are not well established. There is little to no published guidelines for addressing the properties of these materials in terms of pile axial capacity. For example, the FHWA driven pile manual (Hannigan et al. 1996), provides extensive recommendations for analyzing the capacity of piles driven in soil and rock. However, this voluminous manual provides only the following advice for piles driven into intermediate geomaterials.

> "*Piles supported on soft weathered rock, such as shale or other types of very poor or poor quality [rock], should be designed based on the results of pile load tests*."

Prakash and Sharma (1990) recommend that the engineer evaluate the primary supporting "*matrix*" and based on this subjective evaluation, assume the intermediate geomaterial will behave either as rock or as heavily overconsolidated clay. These recommendations are not satisfying or very useful for the engineer faced with designing a bridge supported on deep foundations driven into intermediate geomaterials.

2 Project Objectives and Benefits

Intermediate geomaterials are encountered throughout Montana and it is anticipated that a significant number of future bridge foundations will be founded in these materials, especially in the eastern portion of the state. Because the expense of conducting pile loading tests is cost prohibitive for most bridge projects, MDT geotechnical engineers and geologists could greatly benefit from improved empirical procedures for performing axial pile analyses, for predicting driving resistances, for predicting axial resistance, and for estimating pile tip depth.

The primary objective of this study will be to develop empirically based guidelines for the analysis and design of piles driven into intermediate geomaterials. The guidelines will be developed by conducting back analyses using previously collected data from pile installation projects.

Results from this proposed study will have the potential to improve the reliability and cost effectiveness of a significant number of future bridge foundations in the state of Montana.

3 Project Methodology

Recommendations for estimating empirically based parameters for intermediate geomaterials will be developed by conducting pile axial analyses using measured pile driving data. Data from twelve previous MDT projects will be obtained in the form of foundation reports, pile driving construction records, and pile driving analysis (PDA) records. This data will be reviewed, categorized, and evaluated by conducting back analyses using the computer programs DRIVEN and GRLWEAP. The focus of the analyses will be to develop input parameters for determining pile axial capacity, pile driving hammer and accessory selections, and pile tip elevations.

Task 1 – Project Management/Administration

Communicate (or meet) with project technical panel to discuss various aspects of this project. Establish overall research procedures and methodologies. Additional communications during the project will be through quarterly progress reports and a final report at the end of the project. Attend a meeting at MDT Headquarters in Helena near the end of the project to share the final outcome of the research with the technical panel and other interested MDT personnel. Conduct regular internal project meetings and address administrative responsibilities.

Task 2 – Literature Review

Conduct a literature review to collect and synthesize available published data related to the mechanical properties of intermediate geomaterials (also called formation materials or soft rock). The research team will conduct a thorough literature review to further investigate existing research related to intermediate geomaterials, including a review of any currently available deep foundation design practices. The review will focus on material properties related to deep foundation support and will include a review of applicable case studies and published load test results.

Publications and reports from the Strategic Highway Research Program (SHRP), Federal Highway Administration (FHWA), and state highway agencies will be targeted in the review process. Scientific journals such as *ASCE Journal of Geotechnical and Geoenvironmental Engineering, ASCE Geotechnical Special Publications,* and *Transportation Research Records* will also be utilized. In addition, a detailed scientific web-based search will be conducted using the University Library Search Systems, starting with Info Trac and Compendex.

Task 3 – Data Collection

Records from twelve previous MDT projects will be obtained from the MDT geotechnical group. It is anticipated this information will be in the form of foundation reports, calculation records (axial pile analyses), project plans and specifications, pile driving construction records (hammer blow counts), pile driving analysis records (PDA and CAPWAP). Work efforts in this task will focus on the physical collection of the material as well as organization and preliminary review of data. The budget includes costs for the student research assistant to make two one-day trips to Helena for collecting the project records.

Task 4 – Analysis and Synthesis of Results

The data and information collected in Task 3 will be reviewed, categorized, and evaluated by conducting back analyses using the computer programs DRIVEN (axial capacity) and GRLWEAP (pile driving resistance). The focus of the analyses will be the development of input parameters for determining pile axial capacity, pile driving hammer and accessory selections, and pile tip elevations.

Task 5 – Report

Conclude the study with the preparation of a final research report. Results from the proposed study will be clearly and thoroughly documented in conformance with MDT's standard research report format. Using the engineering basis developed in this study, recommendations will be provided regarding the development of input parameters for axial pile design using DRIVEN and GRLWEAP. A draft report will be submitted to MDT for review, two months prior to the end of the contract period. Comments received from the reviewers will be incorporated into the final document. A Project Summary Report will be prepared after the report is finalized. Research progress reports will be submitted on a quarterly basis.

4 MDT INVOLVEMENT

The Department's assistance will be beneficial to the proposed research project by working with the student researcher to obtain the appropriate project data as described in Task 3.

5 PROJECT STAFFING AND ADMINISTRATION

Dr. Robert Mokwa will be the Principal Investigator for this research project. Dr. Mokwa will be the primary manager and the point of contact with MDT. He will be responsible for ensuring that the objectives of the study are accomplished, implementing the project tasks, and preparing the final report.

Dr. Robert Mokwa: Principal Investigator

Dr. Robert Mokwa is an Assistant Professor in the Civil Engineering Department at Montana State University. Dr. Mokwa is a licensed professional engineer in the state of Montana with over 16 years of research, academic, and industry consulting experience covering a broad range of geotechnical, geo-environmental, transportation, and civil engineering research and design projects. His research skills were recognized by his award of the President's College of Engineering Research Excellence Award from his alma mater, Virginia Tech. He currently teaches classes and conducts research in the areas of geotechnical and materials engineering, deep foundations, soil-structure interactions, frost heave, and site investigative techniques. He has authored 23 technical publications on these topics. In addition to numerous research reports, Dr. Mokwa has written three training manuals for the Montana Department of Transportation. Two relevant studies conducted by Dr. Mokwa for the Montana Department of Transportation include: *Evaluation of the Engineering Characteristics of RAP/Aggregate Blends* and *Soil Air Voids Method for Compaction Control*.

Dr. Mokwa actively participates in many geotechnical professional activities. He is a member of the ASCE Geo-Institute Deep Foundations Technical Committee and the Transportation Research Board Technical Committee on Frost Action. He is a frequent reviewer for the ASCE Geotechnical and Geoenvironmental Journal. In March 2005, Dr. Mokwa was a sponsored speaker/presenter at the *Micro-Geomechanics Across Multiple Scales Workshop*, held in Cambridge, England. This workshop, which was sponsored by the National Science Foundation and the United Kingdom Engineering and Physical Science Research Council, brought together selected geo-professionals from around the world to discuss research needs and the future direction of discovery and applications for the Geotechnical/Geomechanics discipline.

Research Assistant

Dr. Mokwa will be supported by a graduate research fellow who will work on this project throughout its duration. The research assistant will be funded through a competitive grant/fellowship from the Federal Highway Administration (administered by WTI). This proposed study will be the focus of the student's graduate research thesis. Consequently, the student will have additional motivation to conduct first-rate professional work on this project. The student will be involved with all facets of the study under the direction and direct supervision of Dr. Mokwa.

6 References

AASHTO (2005). *AASHTO LFRD Bridge Design Specifications*.

Das, B. M. (2004). *Principles of Foundation Engineering, 5th Ed*. Thomson Brooks/Cole Publishing.

Hannigan, P. J., Goble, G. G., Thendean, G., Likins, G. E., and Rausche, F. (1996). *Design and Construction of Driven Pile Foundations, Vol. 1 and 2*. Federal Highway Administration Report No. FHWA-H1-96-033.

O'Neill, M. W., Townsend, F. C., Hassan, K. M., Buller, A., and Chen, P. S. (1996). *Load Transfer for Drilled Shafts in Intermediate Geomaterials*. U. S. Department of Transportation Publication No. FHWA-RD-95-172.

Prakash, S. and Sharma, H. D. (1990). *Pile Foundations in Engineering Practice*. John Wiley and Sons, New York.

7 PROJECT SCHEDULE

The graduate assistant's thesis work and funding constitute a significant contribution to this study; consequently, the schedule was established to accommodate and provide continuity to the student's program of study. In other words, the schedule was structured to maximize the technical and financial benefits provided to MDT as a result of the student's fellowship and thesis work. The estimated project completion schedule is depicted in Table 1. The total proposed duration of the project is 24 months, with an estimated start date of June 1, 2006, and an estimated completion date of May 30, 2008.

Table 1. Project Schedule

Months	1	2-5	6-8	9-11	12-14	15-17	18-20	21-23	24
Work Tasks									
Project Start	★								
1 – Project Management/Admin.									
2 – Literature Review									
3 – Data Collection									
4 – Analyze and Synthesize Results									
5a – Prepare Draft Report									
5b – Address Comments									
5c – Submit Final Report									★

8 PROJECT BUDGET

The funding request to the Montana Department of Transportation for this proposed research project is $23,896 (itemized costs are provided in Table 2). This amount constitutes 59.7% of the total cost of the project. Matching funds in the amount of $16,144 (40.3% of the total budget) will be provided by the Western Transportation Institute of Montana State University through the MPART agreement. The total estimated cost of the project is $40,041.

These budget amounts do not include graduate student tuition, which is often included in research projects involving student work. As an additional contribution to this project, tuition for the graduate student assigned to this study will be paid using UTC funds through WTI. For the 24 month duration of the project, tuition costs for an in-state graduate student are about $12,100. *Including tuition covered by WTI, the true match for this project is over 50%. Thus, using real dollar amounts, the MSU/WTI team is contributing over one-half of the total cost of the project.*

In-state travel involves two trips to MDT Headquarters in Helena to collect data and one trip for a final presentation to summarize results of the study. Additional resources (counted as expendable supplies) are needed to cover miscellaneous items such as fees for ordering reference materials. Table 3 shows the number of person-hours that will be devoted to each task by research team members. The total number of person-hours needed to complete the work described in this proposal is 1,454. Table 4 shows the dollar amounts associated with each task. Benefits are calculated by multiplying the benefit rate for each individual (Bob Mokwa = 30%, WTI = 31%, Student = 4%), by their total salary.

Table 2. Research Budget

Item	MDT	WTI/MSU Match*	Total
Salaries	$ 15,039	$ 12,936	$ 27,975
Benefits	$ 4,525	$ 517	$ 5,042
In-State Travel	$ 300	$ 0	$ 300
Out-of-State Travel	$ 0	$ 0	$ 0
Expendable Supplies	$ 50	$ 0	$ 50
Subcontracts	$ 0	$ 0	$ 0
Direct Costs	$ 19,914	$ 13,453	$ 33,367
Overhead	$ 3,983	$ 2,691	$ 6,673
Total Project Cost	**$ 23,896**	**$ 16,144**	**$ 40,041**

**UTC Fellowship Graduate Student*

Table 3. Summary of Person Hours

Tasks	Bob Mokwa (PI)	WTI (admin./ management)	Graduate Student	Totals
1. Project Management	104	28	0	**132**
2. Literature Review	10	0	108	**118**
3. Data Collection	30	0	230	**260**
4. Analysis and Synthesis	70	0	520	**590**
5. Reporting	120	14	220	**354**
Totals	**334**	**42**	**1078**	**1454**

Table 4. Summary of Salary and Benefits for Project Team

Tasks	Bob Mokwa (PI)	WTI (admin./ management)	Graduate Student	Totals
1. Project Management	$ 4,264	$ 896	$ 0	$ 5,160
2. Literature Review	$ 410	$ 0	$ 1,296	$ 1,706
3. Data Collection	$ 1,230	$ 0	$ 2,760	$ 3,990
4. Analysis and Synthesis	$ 2,870	$ 0	$ 6,240	$ 9,110
5. Reporting	$ 4,920	$ 448	$ 2,640	$ 8,008
Total Salaries	$ 13,694	$ 1,344	$ 12,936	$ 27,974
Total Benefits	$ 4,108	$ 417	$ 517	$ 5,042
Totals	**$ 17,802**	**$ 1,761**	**$ 13,453**	**$ 33,017**